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Variation Characteristics Analysis of Ultraviolet Radiation Measured from 2005 to 2010 in Beijing China

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1. Introduction

Global ultraviolet radiation (UV) is a small fraction of the total extraterrestrial solar radiation outside the atmosphere. The amount of UV radiation reaching the Earth's surface comprises only a small fraction of global radiation, about 6-7% of global radiation is in the UV-A (320-400 nm) range and less than 1% is in the UV-B (280-320 nm) range. However, UV radiation plays an important role in many biological and photochemical reactions. UV of certain doses could lead to a variety of adverse health and environmental effects (National Radiological Protection Board, 2002; United Nations Environment Programme (UNEP), 1998; Slaper and Koskela, 1997; Outer, 2005). UV radiation also has impacts on the photodegradation of plastics, colorants, paints, and artificial and natural fibers as well as the formation and decomposition of photosensitive urban and industrial contaminants (Cañada et al., 2000). Understanding the amount of UV received by human, plant and animal organisms on the earth's surface is important to a wide range of field such as cancer research, forestry, tropospheric chemistry, agriculture and oceanography (Grants and Heisler, 1997; McKenzie et al., 1991). An understanding of changes in long-term, ground-level UV radiation is required to support assessments of UV radiation-induced health and environmental risks (Slaper and Koskela, 1997). UV radiation-measuring networks are extremely scarce, particularly in the arid and semi-arid, where the effects of UV radiation may be of great importance due to many hours of sunshine throughout the year. Despite its anthropogenic importance and impacts, concern about the amount of UV radiation reaching the Earth's surface has only recently developed, primarily as a result of the thinning ozone layer linked to the depletion of stratospheric ozone in the 1980s (Su et al., 2005).

Numerous factors can influence UV radiation incidence, including cloud characteristics, solar zenith angles, total ozone, aerosol pollution, and surface albedo. Altitude has an important effect on UV radiation (Piazena, 1996; Seckmeyer et al., 1997; McKenzie et al., 2001).Clouds are known to affect the attenuation of UV radiation differently, based on their location, percentage cover, optical thickness, water content, and droplet size distribution. In order to obtain more UV data for other study, lots of studies have focused on quantitative variations in UV radiation and the ratio of UV to global solar radiation (R_s). Additional studies have addressed long-term trends in the variations of UV through reconstructions of past UV radiation based on ground-based and satellite data (Kaurola et al., 2000; Fioletov et al., 2001; Lindfors et al., 2007; Feister et al., 2008;Hu et al., 2010a). In the last few decades, there has been a progressive increase and great concern in the amount of UV reaching the Earth’s surface as a consequence of the thinning of the stratospheric ozone. Despite its anthropogenic importance and impacts, concern about the amount of UV radiation reaching the Earth’s surface has only recently been developed, primarily as a result of the thinning of ozone layer linked to the depletion of stratospheric ozone in the 1980s (Su et al., 2005). UV radiation-measuring networks are extremely scarce, particularly in China.

The objective of this chapter, apart from showing seasonal variations of UV and UV/R_s values in Beijing, based on the reconstruction method, is to develop a long-term data set of UV radiation, and also study variation characteristics of UV in Beijing.

2. Methods

2.1 Site

Beijing, the capital of the People's Republic of China, is located at 39°56' N latitude and 116°20' E longitude. East, North and West of Beijing are surrounded by mountains. The climate of Beijing is an East Asia monsoon type, with cold and dry winters, and hot and humid summers. During winter, the Siberian air masses that move southward across the Mongolian Plateau are accompanied by cold and dry air. In summer, the air mass is hot owing to warm and humid monsoon winds from the southeast, bringing most of the annual precipitation in Beijing area.

The East Asian Monsoon season is the dominating climate of Beijing. In spring (March, April, May), the content of the water vapor in the atmosphere is low and there is little rain in this region. The rainy season begins in June, ends in August and then comes in the dry season. The main rainfall is in July. In autumn (September, October, November), the sky condition is always clear; for Beijing, it is often controlled by the anticyclone. In winter (December, January, February), Siberian anticyclones frequently take place in the Beijing area. Rainless and cloudless conditions are the dominant sky conditions in the region. In this paper, spring and winter are called the dry season because there are few rainfall events in these months. . Summer and autumn are called the humid season, for most of the rainfall occur in these two seasons.

The monsoon starts in July, and ends in October when the dry season begins. There are many active synoptic systems (depressions) in the humid period,. while stabilization system control prevails in the dry season and most days are clear in this period.

In the humid season, the southern wind from the ocean prevails bringing abundant vapor in to the atmosphere, thus the vapor content of the atmosphere is high in this season. Water vapor markedly affects the long wavelength radiation by absorbing them, leaving the UV spectral portion and the short wavelength spectral radiation for possible scattering and reflection. . Consequently, the general decrease in the global radiation could cause the ratio of UV to global radiation to increase as the water vapor increases.

In the dry season, the northern wind from the continent is the prevailing wind bringing dry and cold air. So the vapor content is low in the dry season and the ratio of UV to global radiation decreases as the water vapor decreases.

The seasonal variation pattern of the ratio is that the highest and lowest values appear in summer and winter respectively, and the ratio in autumn is smaller than that in spring. This variation trend is controlled by the water vapor content.

The experimental site is located in down town Beijing area, between the Fourth and the Third Ring Roads. This area is part of downtown Beijing. There are domestic dwellings to the north and south of this site，and a freeway near to it's east. The measurements in this area can represent the average conditions for Beijing. The sampling instruments are installed on a flat platform at the top of the chemical laboratories' building, of the Institute of Atmospheric Physics, Chinese Academy of Sciences.

2.2 Instruments and measurments

A solar radiation observation system was set up on the top of the two-floor building (10 m). R_s, PAR, direct radiation, diffuse radiation, concentration and meteorology parameters(temperature, relative humidity, air pressure) measurements are being carried out in this observatory.. R_s is measured by using a Kipp&Zonen radiometer CM-21 (Delft, The Netherlands). R_s measurements have an estimated experimental error of 2-3%. UV radiation (290–400 nm) is measured using CUV3 radiometers (Kipp & Zonen, Delft, Netherlands) with an accuracy of 5%. All radiation values were recorded at 1-min intervals, and an hourly average value was obtained by integrating the 1-min values. Temperature and relative humidity were measured with HMP45D(Vaisala, Finland),the accuracy of temperature and relative humidity are 0.1 and 3% respectively. The solar radiation parameters observation system is completed with a data acquisition system (Vaisala M520, Finland).

All pyranometers were calibrated by using the 'alternate method' (*Bruce*, 1996). During the process of calibration, we were required to take on-site measurements of global, diffuse, and direct (pyrheliometer) sensor voltages in clear and sunny conditions. The pyrheliometer was calibrated against a reference pyranometer, which had been calibrated against a standard pyrheliometer (PMO6), i.e. absolute irradiance radiometer (Switzerland). This absolute irradiance radiometer is periodically calibrated every five years at the World Radiation Center in Davos, Switzerland.

Manufacturers usually calibrate UV sensors using standard lamps with a known spectral irradiance. The calibration of the UV3 sensor was conducted with a standard light source in standard spectral irradiance that can be traceable to the National Bureau of Standards lamp. A spectroradiometer measures a standard lamp spectral irradiance, and then retrieves the spectral sensitivity under standard lamp conditions. By using the same method, we could deduce the spectral sensitivity under sunshine conditions (equation 2).

$$K_f^D = {V_{D,\Delta\lambda}} \big/ {E_{D,\Delta\lambda}} = \tau_{\Delta\lambda} \cdot S_{\Delta\lambda} \tag{1}$$

where K_f^D is the spectral sensitivity of the spectroradiometer under standard lamp conditions, $V_{D,\triangle\lambda}$ is the respond voltage in response to the standard lamp in $\triangle\lambda$, and $E_{D,\triangle\lambda}$ is the standard irradiance of the standard lamp.

$$K_f^S = {V_{S,\Delta\lambda}}\Big/{E_{S,\Delta\lambda}} = \tau_{\Delta\lambda} \cdot S_{\Delta\lambda} \tag{2}$$

where K_f^S is the spectral sensitivity of the spectroradiometer under sunshine conditions, $V_{S,\triangle\lambda}$ is the respond voltage in response to the standard lamp in $\triangle\lambda$, and $E_{S,\triangle\lambda}$ is the standard irradiance of solar radiation. $\tau_{S,\triangle\lambda}$ is the transmittance of the fiber optic extension cord.

In narrow wavebands, the spectral sensitivity K_f^D is equal to K_f^S, and thus the spectroradiometer and standard lamp can be used to calibrate the quantum sensor. The spectral sensitivity K_f^D for each narrow waveband can be derived from the lamp spectral irradiance. Then, this spectroradiometer can be used to measure the sun irradiance and the integral sun spectral irradiance between 290–400nm to calculate UV. At the same time, the UV sensor to be calibrated measures the respond voltage. The difference between measured results of the quantum sensor calibrated by the spectroradiometer and the new quantum sensor is not more than 1%.

Quality control of the UV radiation measurements was based on two main principles: that observed UV radiation should be less than the extraterrestrial UV radiation at the same geographical location, and that the range of the ratio of UV radiation to R_s should be limited to values between 0.02 and 0.08. Elhadidy et al. (1990) noted that the UV radiation/R_s ratio can be as low as 0.02 on days experiencing high dust levels, while the UV radiation/R_s ratio at the top of atmosphere is 0.08 as derived from integral sun spectral irradiance (Geuymard, 2004). Therefore, the UV radiation/R_s ratio should be between 0.02 and 0.08. Values outside this range were flagged as questionable and excluded from the data set. About 1% of the measurements were eliminated based on these quality control processes. Quality control for R_s was similar to that for UV radiation, and the smallest acceptable value of the ratio of R_s to extraterrestrial global solar radiation was 0.03 (Geiger, et al., 2002).

The extraterrestrial UV_0 can be derived from equation 1 expressed as follow:

$$UV_0 = I_{scuv}\left(\frac{12}{\pi\rho^2}\right)\int_{\omega_1}^{\omega_2} \sin\alpha \quad d\,\omega\,, \tag{3}$$

where α is the solar declination, ω is the hour angle and ρ is correction factor of the Earth's orbit.

$$I_{scuv} = 78 \text{ W m}^{-2}, \tag{4}$$

I_{scuv} has been obtained from the spectral values given by Frohilich and Wherli (Lenobe,1993).

K_s is the ratio of R_s to extraterrestrial broadband solar radiation (H_0) given as follow:

$$K_s = {R_s}\Big/{H_0}\,, \tag{5}$$

All of the calibration works were done at the beginning and the ending of the data collection. At the start and end of data collection, all measurement sensors were cross - evaluated in Beijing. The maximum deviation of CM-11 sensors averaged 1.5% (the average deviation was 1.2%), and the maximum deviation of CUV3 sensors averaged 2.42% (the average deviation was 1.8%).

3. Six-year variation characteristics of UV radiation in Beijing

3.1 Time series of UV radiation and UV/R_s derived from measurement data

The measurement site is located between the northern Third and Fourth Ring Roads in the mega city of Beijing. This site belongs to the Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences. There are domestic dwellings to the north and south of the site and a freeway close to its east side. Measurement instruments were installed on a flat platform on top of the roof (about 10 m) of a building. The Measurement's representation of this site was validated by comparing it to observations results from the China Meteorological Administration (CMA) site (54511) in southern region of Beijing. Figure 1 show the variation characteristics of measurement R_s in IAP and CMA station from January 2005 to December 2008 used for the comparison. From this figure, we find that R_s values at the IAP site were almost same as those at the CMA (54511) station; the largest deviation in average R_s between the two sites was 4.3% and the average deviation was 1.5% (Fig. 1). These results indicated that the measurements at the IAP station are a good representation of the Beijing urban area.

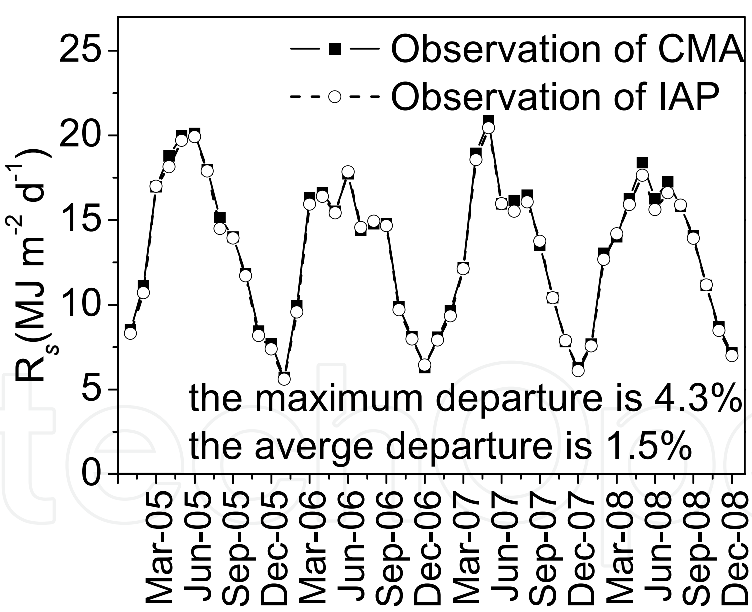

Fig. 1. Comparison of R_s measurements at CMA with that IAP from January 2005 to December 2008 in Beijing.(Hu et al., 2010 a)

The seasonal variation characteristics of UV radiation averaged over 4 years are presented in Fig. 2. UV shows the same seasonal features as that of R_s. The high values of UV and R_s both appear in summer and the low values appear in winter; values in spring and autumn are intermediate. For the diurnal variations, the maximums of Q_p and R_s both appeared around noon each day. There was a good correlation between these two solar-radiation components, by which one of them can be estimated from the other. For the annual variations, one year's variation mode is same as another year's. The minimum monthly average of daily values of UV radiation indicates, in the cool-dry season (i.e., winter period) an increasing trend in the spring with peaks in May. UV radiation levels decrease gradually after the May peak, falling to minimum level in the winter. The annual mean daily values of UV radiation for 6-year period were 0.39 ± 0.16 MJ m^{-2} d^{-1} with the lowest and highest UV radiation values being 1.06 MJ m^{-2} d^{-1} and 0.01 MJ m^{-2} d^{-1}, respectively.

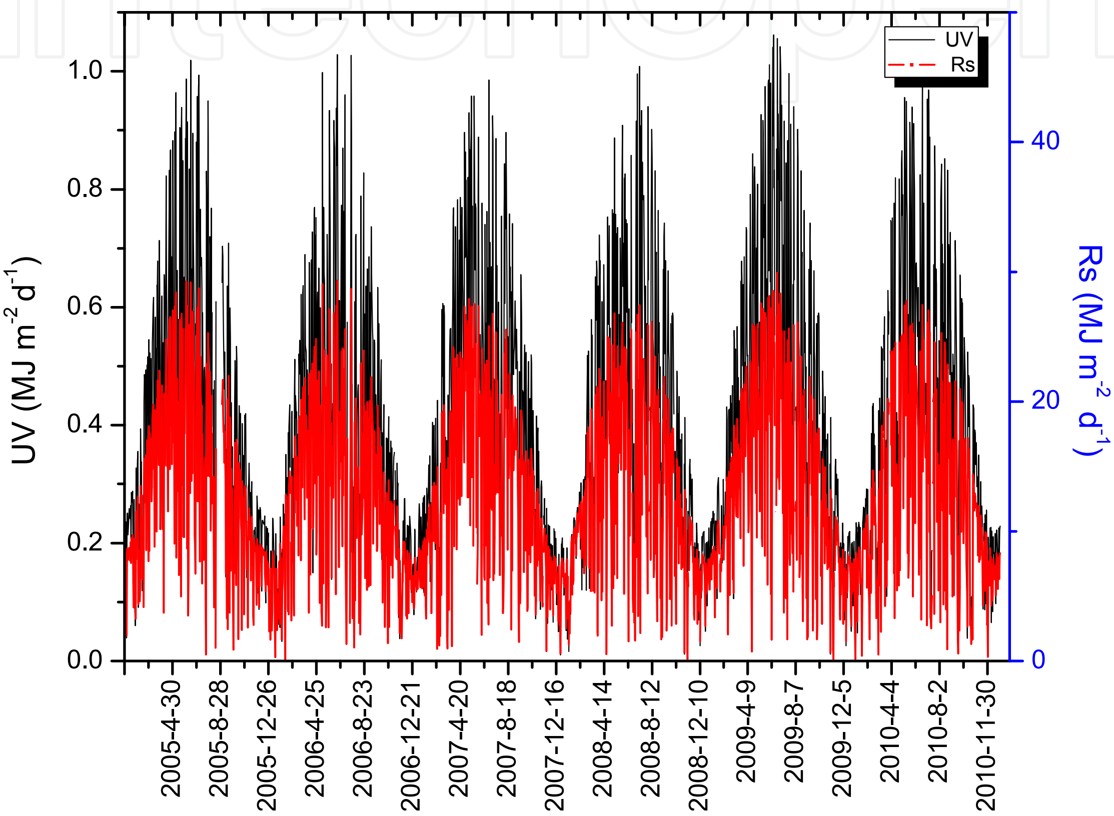

Fig. 2. Variation of UV in Beijing from 2005 to 2010

Figure 3 displays box plots of the monthly statistics of the UV/R_s level in Beijing. The different symbols represent the monthly mean, maximum, and minimum values. There is significant monthly variation in UV/R_s levels. The monthly mean UV/R_s level gradually increases from about 2.7% in November to about 3.7% in August after which it gradually decreases. This seasonal variation of UV/R_s is influenced by seasonal variations in the water vapor content and cloud amount. From spring, the content of column-integrated water vapor generally reaches its maximum in summer, with abundant rainfall, and decreases from August. This variation characteristic is similar to that of UV/R_s. The high values of K_t (the ratio of R_s to extraterrestrial irradiance) occurred in autumn and the low values occurred in summer; the values in spring and winter are intermediate. This seasonal variation pattern of K_t is similar to of column-integrated water vapor content. Under humid and cloudy conditions, the absorption of solar radiation in the infrared region is enhanced because of the increased water vapour content, whereas absorption in the UV region does not vary significantly.

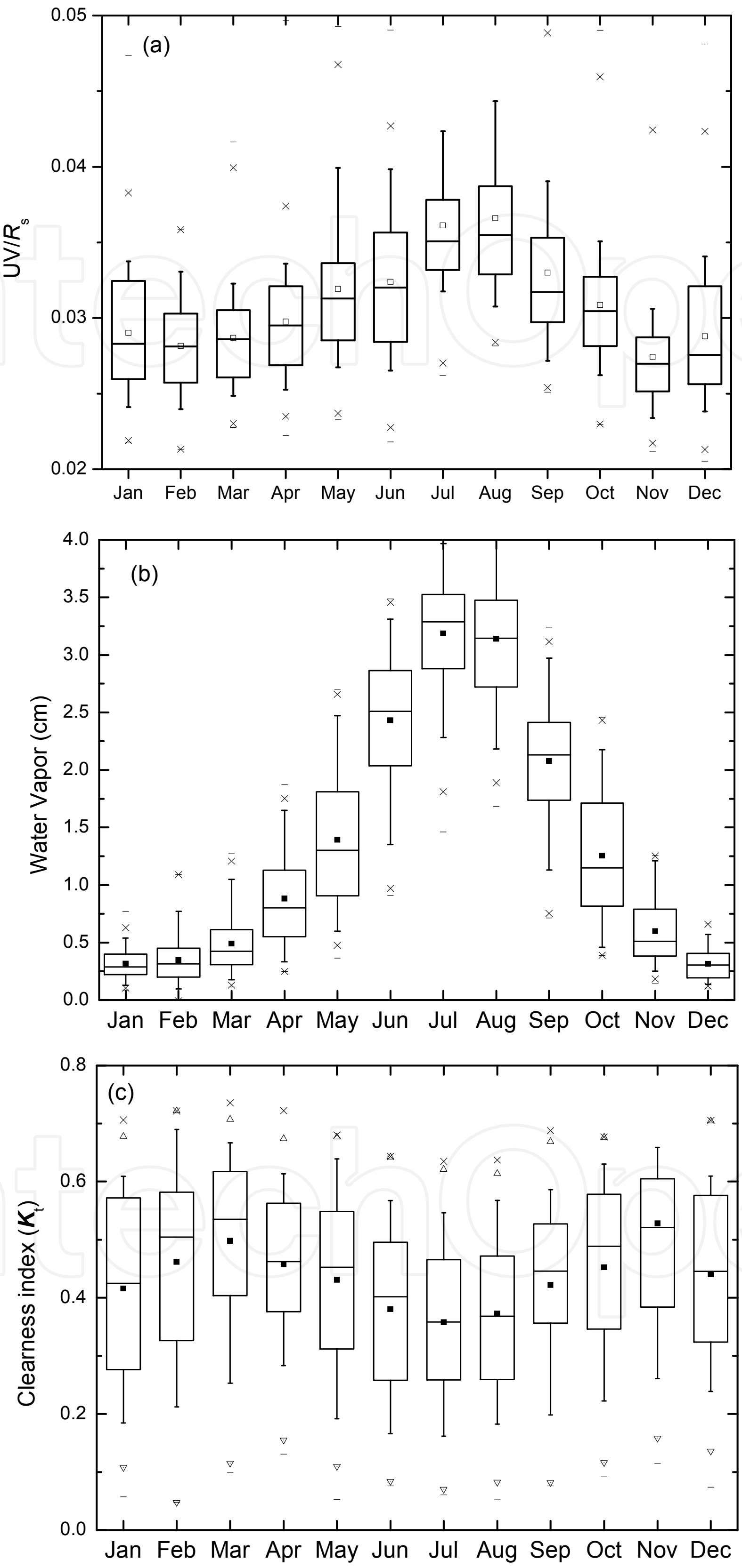

Fig. 3. The graphs of of (a) the monthly ratio of Ultraviolet radiation to solar radiation (b) water vapor content and (c) clearness index. (Hu et al., 2010 b)

In Figure 3, the central bar is the median and the lower and upper limits are the maximum and minimum, respectively.

Most studies use measured values to determine the relationship between UV and R_s and based on this, UV-estimating models are developed. The range of UV/R_s levels must be recalibrated to account for local climatic and geographical differences as well as atmospheric conditions (Udo, 2000). Our study uses direct-measurement UV data to investigate UV radiation properties under various atmospheric conditions in Beijing.

The clearness index, K_t, is defined as the ratio of the total irradiance to extraterrestrial solar irradiance, both defined on a horizontal surface. The K_t ratio is a general indicator of scattering and absorption processes due to aerosols, gases, and clouds that may interrupt the transmission of irradiance through the atmosphere (Liu and Jordan, 1960; Elhadidy et al., 1990).

Fig. 4 depicts hourly UV radiation as a function of the cosine of the solar zenith angle (μ).

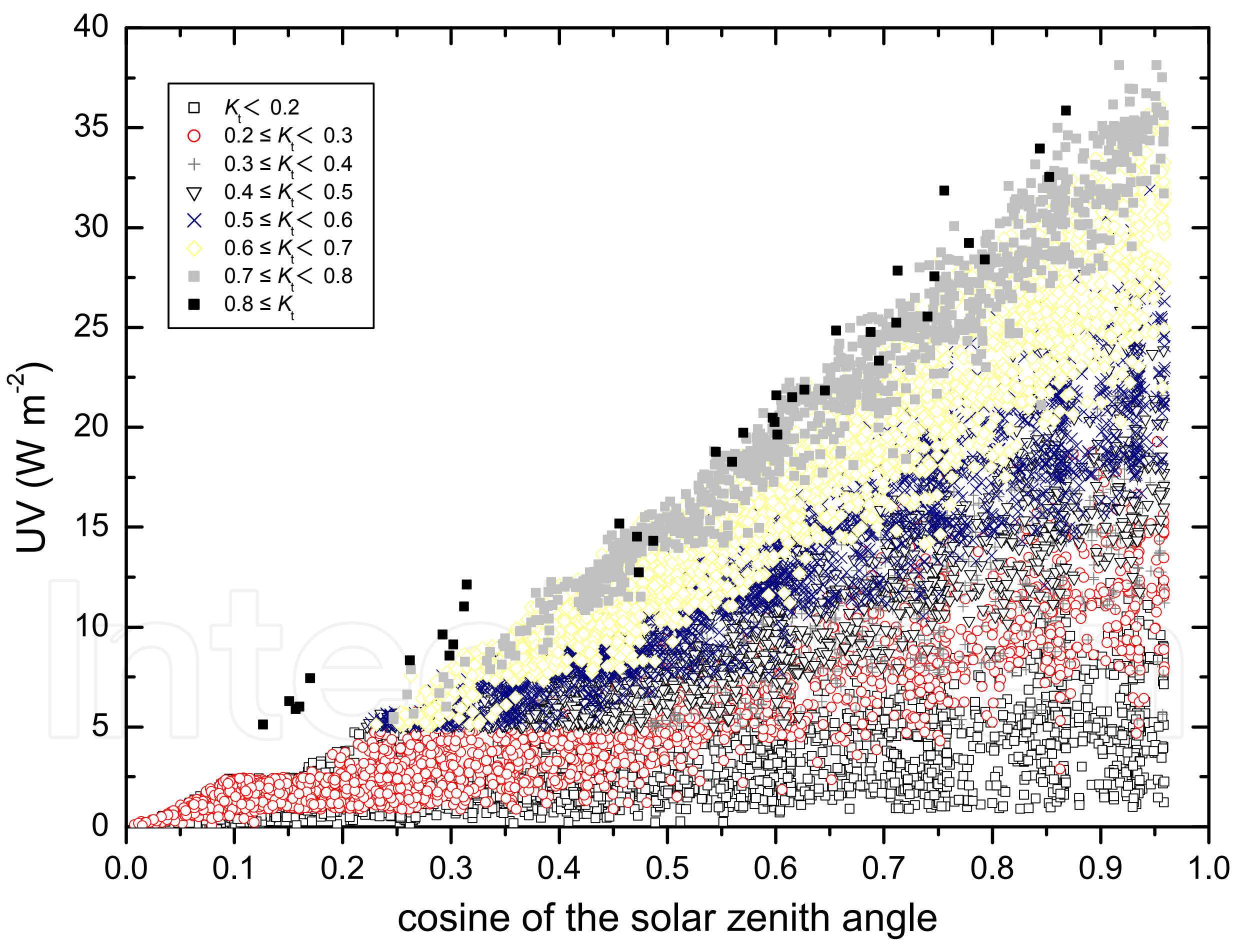

Fig. 4. UV as a function of the cosine of the solar zenith angleat different K_t. Different clearness index (*Kt*) values are represented by different colours. The values of UV radiation within a narrow range of clearness index values increase almost exponentially with the cosine of the solar zenith angle.

Different colour represents data with different K_t values. The results show that UV radiation increases almost exponentially with μ for a specified K_t. Long and Ackerman (2000) used a power law equation to describe the dependence of R_s on clear sky conditions. For a narrow range of K_t values, the relationship between UV radiation and μ can be very well described using the following power law equation:

$$UV = UV_{0m} \times \mu^b \tag{6}$$

where UV_{0m} is the maximum value of UV radiation per unit of μ.

Base on this, hourly UV radiation was estimated using the following equation. The method of establishing an empirical model for UV computation is explained in detail in Hu et al (2010 b).

$$UV = (0.95{+}74\mathrm{K_t}{-}71\mathrm{K_t}^2{+}55\ \mathrm{K_t}^3) \times \mu^{1.031}\ . \tag{7}$$

The daily values of R_s at the Beijing site were measured by the National Meteorological Center, China Meteorological Administration (CMA). The hourly values of R_s, however, were not possible to obtain, therefore, in order to obtain long-period trends in the variation of UV radiation in Beijing, equation 7 was modified as in equation 8 in order to use the daily values of R_s. However, the daily values of R_s could be used to compute daily values of UV using equation 4:

$$UV_{daily} = (8.4{+}3206.8\overline{\mathrm{K_t}}{-}2210.7\ \overline{\mathrm{K_t}}^2{+}2074.8\ \overline{\mathrm{K_t}}^3) \times (\overline{\mu})^{1.031} \times t_d\ , \tag{8}$$

where UV_{daily} is the daily amount of UV radiation, $\overline{\mathrm{K_t}}$ is the ratio of daily R_s to daily extraterrestrial solar irradiance, $\overline{\mu}$ is the average of the cosine of the solar zenith angle from sunrise to sunset, and t_d is the length of daytime in hour.

3.2 Long-periodtrends of ultraviolet radiation in Beijing

The all-weather empirical model was established and validated with measured data at Beijing. Long-term UV radiation data were computed from Beijing observation station, which is located in the southwest Fourth Ring Roads of Beijing. A data set of R_s values collected from 1958–2005 by the National Meteorological Center (CMA) were used in this study.

The Time series of the annual and seasonal averages of UV radiation for spring (represented by April), summer (represented by July), autumn (represented by Oct.), winter (represented by Jan.) are computed for Beijing and presented in Figure 3. Annual mean UV radiation levels decreased from the early 1960s to late 1990s, but began to increase by the late 1990s. The annual mean daily value of UV radiation from 1958-2005 was 0.46 MJ m^{-2} at Beijing station. By the latter half of the 20th century, decreases in UV radiation (0.018 MJ m^{-2} d^{-1} per decade) have been observed. We observed the decrease trends in the long-term annual mean UV radiation as observed from its value of -0.026 MJ m^{-2} d^{-1} per year during the period 1958-1997 and its value of -0.0024 mJ m^{-2} d^{-1} per year during the period 1958-2005.

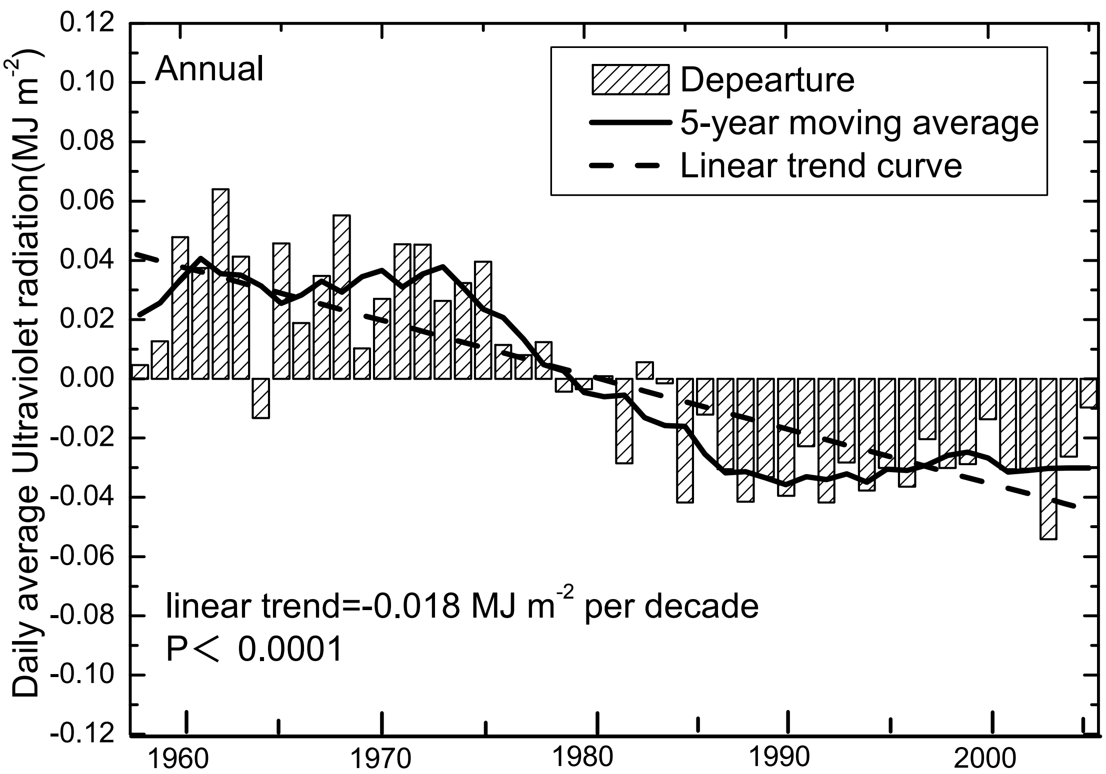

Fig. 5. Long-term variation characteristics of annual average of Ultraviolet radiation for 1958–2005. (Hu et al., 2010 b)

4. Conclusions

The temporal variations in UV radiation using UV radiation and R_s data collected in Beijing over the period January 2005 to December 2010 were studied. The UV radiation levels increased gradually from spring reaching a peak in the summer, and gradually decreased to its lowest levels in winter. Its annual mean daily value was 0.39 ± 0.16 MJ m^{-2} d^{-1}, and its lowest and highest daily values were 1.06 and 0.01 MJ m^{-2} d^{-1}, respectively. Its highest daily value occurred in May and the lowest value occurred in December. The monthly mean daily value of the ratio, UV/R_s, gradually increased from 2.7% in November to 3.7% in August, after which it gradually decreased. The annual mean daily value of UV/R_s was 3.1%.

The annual mean daily value of UV radiation from 1958-2005 was 0.46 MJ m^{-2} d^{-1}. Over the latter half of the 20th century, there have been significant decreases in UV radiation (0.018 MJ m^{-2} d^{-1} per decade).

5. Summary to the chapter

Measurements of total Ultraviolet radiation (UV), broadband global solar radiation (R_S), reflective radiation, net radiation, and Photosynthetically active radiation from 2005 to 2010 in Beijing were used to determine temporal variation characteristics of UV in Beijing. The UV radiation levels increased gradually from spring reaching a peak in the summer, and then gradually declined to its lowest levels in winter. The annual mean daily value of UV radiation was 0.39 ± 0.16 MJ m^{-2} d^{-1}, and the lowest and highest daily average UV radiation levels were 1.06 and 0.01 MJ m^{-2} d^{-1}, respectively. The highest daily values of UV radiation occurred in May while the lowest values occurred in December. The monthly mean daily UV/R_s value gradually increased from 2.7% in November to 3.7% in August, after which it gradually decreased. The annual mean daily UV/R_s value was 3.1%.

A simple, efficient, and empirically derived, all-weather, model is proposed to estimate UV from R_S. The annual mean daily value of UV radiation from 1958-2005 was 0.46 MJ m^{-2} d^{-1}. Over the latter half of the 20th century, there have been significant decreases in UV radiation (0.018 MJ m^{-2} d^{-1} per decade).

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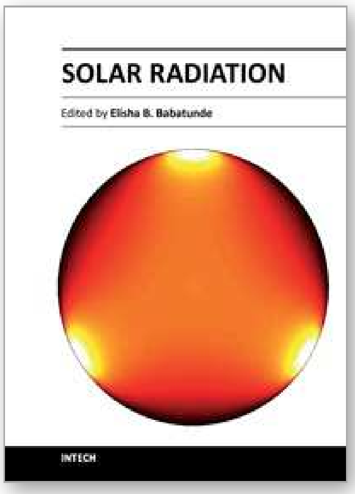

Solar Radiation
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The book contains fundamentals of solar radiation, its ecological impacts, applications, especially in agriculture, architecture, thermal and electric energy. Chapters are written by numerous experienced scientists in the field from various parts of the world. Apart from chapter one which is the introductory chapter of the book, that gives a general topic insight of the book, there are 24 more chapters that cover various fields of solar radiation. These fields include: Measurements and Analysis of Solar Radiation, Agricultural Application / Bio-effect, Architectural Application, Electricity Generation Application and Thermal Energy Application. This book aims to provide a clear scientific insight on Solar Radiation to scientist and students.

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